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Nutrient Composition of Forage Crops

Effects of Genetic Factors and Agronomic Practices

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Effects of Genetic Factors

By Glenn W. Burton[1]

ABSTRACT

Concentrations of the forage nutrients protein, carbohydrates, minerals, vitamins, and antiquality components such as tannin are genetically controlled and can be altered by selection. Digestibility, palatability, intake, and plant structure, which determine the percentage of nutrients in a forage that are available to the animal consuming it, are also genetically controlled. Generally, inheritance seems to be polygenic. Index terms: forage plants, livestock nutrition, plant genetics, plant nutrients.

INTRODUCTION

Nutrients in forage crops are the plant substances that are nutritious to the animals that consume them. For many years, chemists analyzing forages characterized nutrients as protein, fat, fiber, nitrogen-free extract, and ash or mineral matter. In recent years, the fiber and nitrogen-free extract have been divided into lignin, cellulose, starch, sugars, pentosans, etc., as chemists have tried to pinpoint those elements that influence animal nutrition. Minerals have been divided to include elements, such as calcium, magnesium, phosphorus, and potassium, that are known to affect animal health. And vitamins, such as carotene (provitamin A), that occur in forages are now being studied as nutrients that affect animal growth. Many antiquality compounds, such as tannin and various alkaloids, are also being studied.

Like other plants, forage crops vary in nutrient composition. Species differ, as do cultivars within species, in content of all nutrients. Nutrients in forages are genetically controlled, so their content can be altered by changing their genetics. Because modifying the environment and management of the forage also affects its nutrient composition, the nutrient content of a forage at any specific time results from the interaction of its genetic factors with the environment. The nutritional value of a forage is also indirectly influenced by several genetic factors unrelated to nutrient content. The forage's digestibility, a genetically controlled trait, determines how much protein in the forage will be available to the animal. The plant's structure, leafiness, and cuticle thickness are genetic characters that determine how much of a forage an animal can use. Such other genetically controlled traits as pest resistance and photoperiodic response also indirectly influence the availability of the nutrients in a forage.

Some forages are so high in unpalatable compounds, such as tannin, that animals refuse to eat them or eat less than required for good growth. The concentration of these compounds is genetically controlled and can be altered to improve the usefulness of the forage. Forages lacking specific unpalatable compounds still differ in palatability. Because palatability determines the amount of forage an animal will

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eat each day, it is an important genetic trait that indirectly determines the value of the forage.

"Forage quality" is a general rating of a forage's usefulness to animals. Palatable forages high in digestible nutrients have excellent quality; those forages low in nutrient content have poor quality. The quality of a forage cultivar is difficult to characterize because it is determined by the interaction of many hereditary and environmental factors. Forage quality is never constant. Because it declines as the age of a forage increases, a meaningful characterization of the forage's quality must include its age when sampled and a description of the management used to grow it.

GENETIC FACTORS DIRECTLY AFFECTING FORAGE NUTRIENT CONTENT

Protein

Animals build proteins from the amino acids separated from plant proteins as they are digested. Ruminants, like cattle and sheep, that eat most of the forage crops have a rumen in which micro-organisms first consume much plant protein and convert it into proteins in their own cells. This bacterial protein can later be used in the animal's nutrition and can supply essential amino acids that may be lacking in the plant proteins. For the ruminant, then, the quality of a forage depends on how much digestible protein it has.

Legume forages usually contain at least as much protein as animals need. The nitrogen essential for protein production in plants is supplied in adequate amounts by the nitrogen-fixing bacteria in nodules of well-inoculated legumes. But protein production in grasses depends mainly on fixed nitrogen in the soil; most soils do not have enough. On such soils, grass yield and protein content are determined by the amount of fixed nitrogen applied to the grass as fertilizer. For example, 'Coastal' bermudagrass, *Cynodon dactylon* (L.) Pers., fertilized with 0, 100, 300, 600, and 900 pounds of nitrogen per acre in a good growing season at Tifton, Ga., and cut at 6-week intervals produced 1.6, 4.8, 8.1, 10.5, and 11.2 tons per acre of dry matter containing 7.6%, 7.8%, 11.3%, 13.8%, and 15.3% protein (Prine and Burton 1956). The age of the grass when it is cut, or length of cutting interval, also affects yield and protein content. For example, 'Coastal' bermudagrass fertilized with 600 pounds of nitrogen per acre and cut every 3, 4, 5, 6, 8, 12, and 24 weeks contained 18.5%, 16.4%, 15.4%, 13.3%, 10.7%, 9.0%, and 8.4% crude protein (Burton et al. 1963). So, how genetic factors influence protein content can only be ascertained when all genotypes being studied are grown in the same environment and are sampled at the same age.

Genetic factors influence protein content of forages in many plants. Cooper (1961) observed significant genetic differences related to crude protein content in plants within families of ryegrass, *Lolium perenne* (L.), and orchardgrass, *Dactylis glomerata* (L.), and concluded that varieties with higher protein content could be developed by breeding. At Tifton, 61 bermudagrass hybrids in a replicated yield trial harvested on August 3 had protein contents ranging from 9.1% to 12.9% with a 5% LSD of 0.8% (G. W. Burton, unpublished data). Heinrichs and Troelson (1965) studied the leaves of 100 alfalfa plants selected from a segregating population of hybrids of *Medicago sativa* (L.) × *M. falcata* (L.) and found protein content ranging from 21.7% to 32.2%. Protein in the stems of the 100 plants ranged from 7.3% to 12.9%. The correlation coefficient between crude protein and crude fiber was -0.933 in the leaves of the 100 plants studied but only -0.446 for the stems. Heinrichs and Troelson concluded that to change the chemical makeup of alfalfa, selection would have to be based on chemical analysis because visual traits could not be positively correlated with nutrient content.

Carbohydrates

Carbohydrates are the chief energy source and three-fourths of the dry matter in forages. All animals can digest the sugar and starch carbohydrates and convert them to energy, but no animal digestive enzyme can break down cellulose, hemicellulose, and pentosan carbohydrates. These compounds must first be attacked by bacteria and protozoa in the first two compartments of the stomach in ruminants, in the caecum and colon in the horse, and in the large intestine of other animals. Micro-organisms break down the cellulose, hemicellulose, and pentosans into organic acids, simple sugars,

gases (carbon dioxide and methane), and heat. Animals can use the sugars and organic acids for food. Most micro-organisms that break down forages are later digested in the true stomach (abomasum) and small intestine and supply additional food.

Forages differ in the kinds and amounts of carbohydrates that they contain. Young, actively growing tissues of most plants contain sugars. The tender base of the stem from emerging seed heads in grasses usually tastes sweet. As these tissues grow older, the sugars change to starch, hemicelloluse, and pentosans. At any comparable physiological stage of development, genotypes will differ in the proportion of sugars or other carbohydrates. Cooper (1961) found significant differences in soluble carbohydrates among cultivars of ryegrass and orchardgrass. He also noted that genetic variation within families of these grasses was large enough that cultivars could be bred to have more of the soluble carbohydrates than the family mean.

Forages are generally too low in digestible energy to produce maximum weight gains in the animals consuming them. So forages are supplemented with high-energy grains to permit animals (including ruminants) to make maximum daily gains. How much the digestible energy of a forage can be improved by breeding and how much the performance of the animals should improve have not been established.

Minerals

Several mineral elements are essential for animal health and normal development. Those elements essential for beef cattle are calcium, phosphorus, potassium, sodium, chlorine, sulfur, magnesium, iron, manganese, zinc, iodine, selenium, molybdenum, copper, and cobalt (U.S. National Research Council. Committee on Animal Nutrition 1976). Forages planted in improved pastures and hay meadows usually contain enough of these minerals to meet the needs of the animals consuming them. Generally, legumes contain more minerals than grasses, and young forage contains more minerals per unit of dry matter than old, mature forage of the same species.

The amount of each of the essential minerals in forage plants is probably under genetic control and can probably be increased by plant breeding. But little research has been done that can verify these assumptions. Butler et al. (1962) measured the content of 12 elements (nitrogen, phosphorus, sulfur, sodium, potassium, calcium, manganese, aluminum, copper, titanium, iron, and zinc) in 7 ryegrass plants derived from crosses between *Lolium multiflorum* (L.) and *L. perenne* (L.) and found significant differences among clones for all but iron and potassium. Heritabilities ranged from 0 for potassium to 0.792 for nitrate content and were large enough for nitrate, sulfur, and sodium to indicate that the content of these elements could be easily modified by plant breeding. Butler and Glenday (1962) found significant differences (more than 10-fold) in iodine content in the leaves of 13 randomly selected perennial ryegrass plants grown on the same soil. Analysis of the data proved that iodine content in this important pasture species is under genetic control and can be improved by breeding. Cope (1962), studying the content of nitrogen, calcium, and magnesium in 150 plants of sericea lespedeza, *Lespedeza cuneata* (Dum. de Cours.) G. Don., found heritabilites of 0.62 for nitrogen, 0.44 for calcium, and 0.24 for magnesium. These values show that the content of nitrogen, calcium, and magnesium in sericea lespedeza is heritable and can be modified by selection.

Grasses and forbs growing naturally in the ranges in many parts of the world are deficient in one or more essential mineral elements. Generally, the element deficient in the forage is also deficent in the soil in which the forage is growing. Although cultivars capable of extracting more of the deficient element from the soil could probably be bred, they would soon exhaust the deficient element in the soil and be no better than the forages now growing there. The costs of developing such cultivars and introducing them into the range would very likely exceed the benefits to be derived from them. Fertilizing forages in rangelands with the deficient mineral element will raise the content of the element in the forage. Usually, however, it is cheaper to satisfy the mineral needs of the animals consuming the forage by giving them a mineral mixture that contains the deficient element.

Vitamins

Vitamin A is essential for the breeding, development, and finishing of beef cattle. Carotene

(provitamin A), present in all green forage, can satisfy the vitamin A requirements for beef cattle and other animals that consume forage. Chemical analysis of forage cut at 2-, 4-, 5-, and 6-week intervals from replicated plots of several bermudagrass hybrids in one season at Tifton, Ga., revealed that they differed significantly in carotene content (G. W. Burton, unpublished data). An average of all cutting intervals showed that the hybrid with the highest carotene content contained 70% more carotene than the hybrid with the lowest content. These data indicate that carotene content in forages is under genetic control and can be increased by breeding.

The vitamin D requirements of cattle are usually satisfied by exposing them to direct sunlight or supplying them with sun-cured forages; and milk usually meets the B-vitamin requirements of young calves during the first 8 weeks of their lives while they are developing a functional rumen (U.S. National Research Council. Committee on Animal Nutrition 1976). Rumen bacteria are then able to synthesize enough of the B vitamins to satisfy the needs of the animal in most feeding regimes. But severe deficiencies in essential nutrients such as protein and cobalt in the feed may impair rumen fermentation so much that not enough B vitamins will be synthesized. So overcoming protein and mineral deficiencies in forages by breeding may both indirectly and directly improve the nutrition of the animals.

Antiquality Components

One of the first antiquality components found to damage forage usefulness was coumarin, a chemical compound that makes sweetclover, *Melilotus alba* Deev. and *M. officinalis* (L.) Lam., bitter and unpalatable to most livestock. And when sweetclover hay is improperly cured, coumarin decomposes to dicumarol, a blood anticoagulant. Livestock eating such hay develop a bleeding disease that could be fatal. To reduce the coumarin content in sweetclover, W. K. Smith, an agronomist for the U.S. Department of Agriculture and the University of Wisconsin, crossed sweetclover with a wild European species, *M. dentata* (W. & K.) Pers.; the first hybrids were so deficient in chlorophyll that they had to be grafted on normal sweetclover plants so they would grow and produce seed (Crops and Soils 1961). Through a series of backcrosses of sweet segregates to bitter sweetclover, Smith was able to develop the 'Denta' cultivar that contained only a twentieth of the coumarin found in other sweetclovers.

Tannin is a chemical compound in many forages that imparts a bitter taste, reduces intake, and, in high concentrations, lowers digestibility. Stitt (1943) observed signficant differences among clones of sericea lespedeza and suggested that tannin content in this species could be reduced by selection. Cope (1962) measured the yield and tannin content of 150 plants of sericea lespedeza, found significant differences among plants, and reported heritabilities ranging from 0.64 to 0.71. He concluded that "there appears to be no serious limitation to the development of high yielding, low tannin varieties."

Blue lupine, *Lupinus angustifolius* L., sometimes used as a winter cover crop to produce nitrogen for summer growing crops, contains a bitter alkaloid that makes it both unpalatable and poisonous to cattle. When it is homozygous, a single recessive gene, *incundus*, can remove this alkaloid and make blue lupine forage a good grazing crop and blue lupine seed a high-protein feed for swine. When blue lupine was first developed, both bitter and sweet blue lupine had blue flowers and gray seeds. A small mixture of bitter lupine in sweet lupine makes it useless and dangerous as a feed for livestock. To mark sweet lupine so mixtures of bitter plants could be detected, Forbes et al. (1964) transferred the *incundus* gene by hybridization to a white-flowered, white-seeded, anthocyanin-free mutant of bitter blue lupine. The resulting sweet cultivar, 'Blanco', with white seeds and flowers and without anthocyanin in the foliage can be easily identified at any stage of its development.

Hovin and Buckner (1976) and Martin et al. (1976) showed that the indole alkaloid concentration in reed canarygrass, *Phalaris arundinacea* L., is negatively correlated with relative palatability and live-weight gains of grazing animals. Barker and Hovin (1974) analyzed 36 unrelated parent clones of reed canarygrass for indole alkaloid content and found it to vary from 0.17% to 1.37%. Heritabilities for indole alkaloid content ranged from 0.67 to 0.72. Because narrow-sense heritabilities were nearly as large as corresponding broad-sense heritabilities, Barker and Hovin concluded that

genetic variance was largely additive. Control of inheritance seemed to be polygenic.

Bush et al. (1972) have shown that perloline, an alkaloid that may inhibit digestibilty of forage in ruminants, may explain the erratic performance of cattle grazing pure stands of tall fescue, *Festuca arundinacea* Schreb. Hovin and Buckner (1976) have found that perloline content is "controlled by relatively few genes with dominance for low concentration" and is apparently "inherited independently of alkaloids of the pyrrohizidine group and is not associated with agronomic characteristics." Buckner is developing cultivars with low perloline content.

No one knows how many antiquality compounds exist in forages. But, as these compounds are isolated and identified, plant breeders will probably be able to lower their levels in a forage and improve its quality.

GENETIC FACTORS INDIRECTLY AFFECTING FORAGE NUTRIENT CONTENT

Digestibility

Digestion is all the changes a forage must undergo in the digestive tract of an animal before it can be absorbed and used in the animal's body. Some forage components, such as starch and the sugars, digest rapidly and completely. Other components, such as lignin and cuticle, digest very little and very slowly. The digestibility of a forage determines how much of its nutrients the animal can use. How easily and quickly a forage can be digested determines its quality and the animal's performance (growth, weight gain, milk yield). Young forages are more digestible than old forages. Species and their cultivars differ from each other in digestibility even if they are the same age and have been grown in like environments. Increasing the digestibility of a forage a few percentage points may greatly increase animal performance.

The percentage of a nutrient or forage that is digestible is called the digestion coefficient. This is determined experimentally by feeding measured quantities of the forage to animals that will use it for several days, collecting the feces, analyzing both, and determining by difference the percentage of nutrients that were digested. The cost of producing enough of one forage and conducting such digestion trials with enough animals to give a dependable digestion coefficient prohibited study of the inheritance of forage digestibility until Tilley and Terry (1963) developed their two-stage technique for the in vitro digestion of forage crops.

Since 1963, several forage breeders have used the Tilley and Terry IVDMD (in vitro dry matter digestibility) method, or a modified version, to estimate the digestibility of forage genotypes within a species. McLeod and Minson (1969) and others have found that the IVDMD method can accurately predict the digestibility of a forage. Cooper et al. (1962) used the Tilley and Terry method to estimate the digestibility of individual plants and families of ryegrass and orchardgrass. Significant differences in IVDMD were found among genotypes within each species, but the heritability of digestibility in ryegrass was low. In orchardgrass, however, the heritability for IVDMD was high enough to indicate potential for genetic improvement. Ross et al. (1970), studying the IVDMD of a six-clone diallel in smooth bromegrass, *Bromus inermis* Leys., found high heritabilities for this character and concluded that genotypes with superior digestibility can be selected and synthetic varieties with higher IVDMD can be produced. Sleper et al. (1973), studying a different six-clone diallel of smooth bromegrass, found heritabilities for IVDMD ranging from 0.64 to 0.78 and concluded that genetic improvement of IVDMD in this grass is possible. Thirty-six single crosses, synthetics, and cultivars of maize, *Zea mays* L., grown in Minnesota and sampled 45 days after anthesis gave IVDMD values ranging from 70.9% to 77.2% (Roth et al. 1970). The data indicated that maize varieties could be bred for silage; these would be better than those developed for grain alone. Barnes et al. (1971) compared the IVDMD of 35-day postsilk whole plants of maize that were near-isogenic for normal plants or for three different homozygous brown midrib mutants bm_1, bm_3, and bm_1bm_3. The IVDMD's of 68.3% for the normal plants and 72.0%, 75.5%, and 77.8% for the mutants were significantly different. So the single gene, brown-midrib mutants that reduce lignin content in maize forage and increase forage digestibility can be transferred by hybridization and selected visually to improve the quality of maize

silage. Gill et al. (1967) studied the inheritance of IVDMD in a 10-clone diallel of *Medicago sativa* L. and reported a range in IVDMD among crosses of 63.3% to 69.5% in the June 21 harvest and 72.7% to 77.5% in the September 17 harvest. Mean squares for both general and specific combining ability were significant. Although the data suggested that digestibility could be increased by selection, more progress could be made in increasing total digestible units per unit of area by selecting for yield.

Burton and Monson (1972) studied the inheritance of dry-matter digestibility in bermudagrass and concluded that dry-matter digestibility appears to be conditioned by several genes that show little dominance. Heritabilities for a seasonal average of two to four clippings ranged from 0.27 to 0.69; so the dry-matter digestibility can be increased by breeding. Out of this breeding program came 'Coastcross-1' bermudagrass, a sterile, vegetatively propagated F_1 hybrid that was 12% more digestible than 'Coastal' (Burton 1972). In the first feeding trial, steers fed dehydrated 'Coastcross-1' made 30% better average daily gains than those fed 'Coastal'. Such a gain would be expected from a forage 12% more digestible than the check but otherwise like it. In a 4-year replicated grazing trial, steers grazing 'Coastcross-1' averaged 34% better average daily gains and live-weight gains per acre than those grazing 'Coastal'. The dry-matter yields of both grasses were similar. To find out how much more the IVDMD of bermudagrass might be improved, Burton and Monson (1972) did a study in which they determined in 2 consecutive years the IVDMD for 5-week-old, second-harvest forage taken from a world collection of over 500 genotypes. They found the 2-year average IVDMD's for these plants ranged from 40% to 69% with a median class value of 52%. Only eight of the genotypes had IVDMD's greater than 63%.

So the digestibility of most forages can probably be improved by screening large populations of plants with the IVDMD method. The experience with 'Coastcross-1' bermudagrass suggests that varieties with significantly higher digestibilities will give even greater increases in animal performance if the increase can be achieved without sacrificing yield or other important characters.

Palatability and Intake

Significant, repeatable differences in the palatability of clones or varieties of a grass species, as measured in a cafeteria test (where animals have free choice and may demonstrate a preference), have been observed by many. Burton (1947) noted significant differences among nine clones of bermudagrass compared in replicated plots in 1944. The dairy cows tested showed a distinct preference for 'Coastal' bermudagrass over the common variety. Buckner and Burrus (1962), selecting according to the intensity of grazing in a spaced-plant nursery, were able to produce strains of tall fescue with improved palatability to cattle. Thomas et al. (1965) and Asay et al. (1968) observed significant heritable differences in the palatability of reed canarygrass clones compared under cafeteria grazing. O'Donovan et al. (1967) detected positive relationships between palatability and intake of organic matter in reed canarygrass. But Barnes and Mott (1970) found voluntary dry-matter intake was significantly greater for palatable clones in only one of four harvests frozen and fed freely to lambs.

Increasing the animal's forage intake (quantity consumed per unit of time) should increase the animal's performance. It seems logical to assume that the forage preferred by animals in a free-choice cafeteria test will be the one producing the highest intake and the best performance when fed in pure stand. But experience has shown that differences in animal preference for cultivars in cafeteria tests are limited in predicting intake and performance of animals confined to pure stands. This failure of classification of cafeteria palatability to agree with intake and performance could be due to differences in digestibility. For example, in replicated cafeteria tests, cattle have greatly preferred pearlmillet, *Pennisetum americanum* (L.) Leeke, without trichomes (Burton et al. 1977). But the recessive gene, *tr*, that removes the trichomes increases the cuticle's resistance to the penetration of rumen organisms and makes the green leaves significantly less digestible than those of pearlmillet with trichomes. Such forage will remain in the rumen longer than the normal forage and will reduce the amount an animal can eat in a day. So improved palatability can be offset by reduced digestibility.

Forage cultivars within species do differ in palatability and intake, which are characters under genetic control. A dependable, inexpensive technique for estimating the intake of many plants must be found, however, before plant breeders can improve intake by breeding.

Plant Structure

Restructuring the plant with the aid of simply inherited characters is one of the easiest methods of improving forage quality. Dwarfing pearlmillet with the recessive d_2 gene reduced internode length and plant height 50% and increased leaf percentage from 54% to 81% in boot-stage forage (Burton et al. 1969). Heifers consumed 21% more of the dehydrated boot-stage dwarf millet and made 49% better average daily gains than other animals eating isogenic tall millet. The dwarf millet also gave better average daily gains when grazed. And though the dwarf millet produced only 80% as much dry matter, live-weight gain per acre was as much as that for isogenic tall millet.

On sorghum, *Sorghum bicolor* (L.) Moench., foliage, the bloom can be removed by a single recessive gene. Green leaves of three bloomless sorghums grown in Georgia were 22% more digestible (by a modified IVDMD technique) than bloom-covered green leaves of their normal isogenic counterparts (Cummins and Dobson 1972). The bloomless character can be screened visually. Research is underway at the Coastal Plain Station, Tifton, Ga., to develop a bloomless hybrid of sorghum and sudangrass, *Sorghum bicolor* (L.) Moench., that should have much better quality than that of varieties currently in use.

Roth et al. (1970) studied the genetic variation of 5 forage-quality traits in 36 maize single crosses and cultivars and observed a negative correlation between stalk strength and forage quality. So stalk strength, a highly desirable heritable trait in maize for grain, must be lowered if forage quality in maize for silage is to be improved. Because stalk strength is under genetic control, developing better maize cultivars for silage should be possible by breeding for reduced stalk strength; but enough strength should be retained to keep the plant standing until it has reached the proper stage for silage production.

Pest Resistance

Resistance to the pests that attack forages is highly heritable and is often controlled by only one or two genes. Pests (both diseases and insects) that destroy forage leaves reduce the quality and quantity of forage available for animal feed. Increasing resistance to such pests may be expected to improve forage quality if it does not hinder animal performance.

Foliage diseases that kill leaf tissue will probably reduce forage quality. *Colletotrichum graminicola* (Ces.) G. W. Wils., which killed an estimated 10% of sudangrass leaves at Tifton, Ga., in the summer of 1952, destroyed 9% of the protein and fat and increased the lignin content of the leaves 20% (Burton 1954). In the summer of 1972, pearlmillet growing at Tifton, Ga., was heavily attacked with rust caused by *Puccinia substriata* Ell. & Barth var. *indica*. Not only did it destroy leaf tissue and the nutritive value of the forage, it made the forage so unpalatable to livestock that they would have lost weight had they received no other feed (G. W. Burton, unpublished data).

Photoperiod

Photoperiodism is the influence of light and dark periods on the growth of a plant, particularly its floral initiation. Many forages have photoperiodism (Burton, unpublished data). For example, selected clones of bermudagrass and guineagrass, *Panicum maximum* Jacq., from near the Equator in Africa remain vegetative in long days and initiate seed heads only as the day length is close to 12 hours or less. Certain varieties of sorghum and pearlmillet from equatorial Africa also show this phenomenon. But, a Ladino clover, *Trifolium repens* L., that seeded well during the long summer days in Oregon (latitude 44° N.) flowered very little during the shorter days at Tifton, Ga. (latitude 31° N.).

In pearlmillet, day-length response, a highly heritable character may be conditioned by one gene—the day-neutral response would be recessive (Bilquez 1963) or by several genes that act additively with little, if any, dominance (Burton 1966). From short-day (12 hours) × day-neutral (14.5 hours) hybrids of plants having genes showing little dominance, it has been possible

to develop pure lines needing intermediate day lengths. A study of the yield and quality of early- and late-maturing, near-isogenic populations of pearlmillet revealed that a millet reaching anthesis in 78 days should be a better forage than one maturing in 53 days (Burton et al. 1968). In this study, the later that millets matured, the better their yield (9% to 19%) and seasonal distribution as forage; they were also easier to manage, more persistent, leafier, higher in protein content, and more digestible. 'Tiflate' pearlmillet is a synthetic variety bred to remain vegetative until the day length is 12 hours or less (Burton 1972). It has all the advantages, then, of late-maturing millets. Because of its short-day photoperiod sensitivity, 'Tiflate' will not mature seed before December in the continental United States, regardless of the date planted. So frost injury prevents growing seed in most of the United States. But, when planted in frost-free areas nearer the equator with its shorter days, 'Tiflate' matures quickly on short stalks that are easy to harvest, and it gives excellent seed yields.

CONCLUSION

All nutrients in forages are under genetic control. The information reported here suggests that significant differences in the content of all nutrients may be expected among the variable populations of each forage species. Although some single genes such as d_2 and *tr* in pearlmillet can significantly affect the nutrient content of a forage, the examples presented suggest that several genes control the percentage of most nutrients in each species.

Forages are grown to feed livestock. Forage breeders must be concerned, therefore, with altering their species to increase the yield of animal product. They can do this by increasing the yield of forage dry matter, by increasing the quality of the dry matter, or both. Quality is determined largely by the quantity of digestible nutrients in a forage. We have found that percent of dry-matter digestibility as measured by the IVDMD technique correlates well with animal weight gains in forages that do not possess antiquality characteristics such as tannin. Properly fertilized and managed forages usually contain adequate amounts of most nutrients. Therefore, percent of digestible dry matter (largely carbohydrates and protein), most frequently deficient in forages, will continue to be the nutrient complex that we will try to increase in our grass-breeding program.

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Nutrient Composition of Forage Crops

Effects of Agronomic Practices

By Warren G. Monson[1]

ABSTRACT

The nutrient content of forage crops is greatly influenced by how they are grown, fertilized, and used. Proper fertilization insures that the plant will get enough nutrients for growth and for the animal that consumes it. Nitrogen fertilization on grasses helps maintain protein levels. The forage's age when it is used markedly affects its digestibility. For highest quality, a forage should be grazed or harvested at the youngest stage that will give an economic yield. Index terms: forage management, forage plants, livestock management, livestock nutrition, plant nutrients.

INTRODUCTION

The genetic makeup of a forage plant establishes its potential. But environment and management determine whether or not the genetic potential is realized. Since forages have high amounts of structural carbohydrates that man cannot digest, they must first be processed by ruminant animals (Moore et al. 1967). But a kilogram of total digestible nutrients in forage or a digestible calorie of forage is generally used less efficiently than the digestible equivalent of feed grain (Van Soest 1973). So currant research emphasizes the improvement of forage quality, either by improving the plant or by improving management.

Forage constituents can be divided into two nutritional classes—the highly digestible cellular contents (protein, sugars, starch, and organic acids) and the less easily digested fibrous or cell wall components. So any management practice that will increase the amount of cellular contents in a forage should improve its quality as a feed for ruminants. But some good quality fiber must be kept in the diet for proper rumen function and feed efficiency and to maintain butterfat level.

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FORAGE AGE

The chemical makeup of forage plants changes as they mature from the vegetative stage. Most of this change is caused by an increase in the ratio of cell wall to the more soluble cell contents. Forage quality is also decreased because lignification of the cell wall increases. A high degree of lignification protects most of the cell-wall polysaccharide from fermentation by rumen micro-organisms and also makes disintegrating the plant by mastication and rumination more difficult physically. As the plant matures, then, the ruminant cannot digest as much of the cell wall; so the digestion rate slows, and the animal is able to eat less.

The nutritive value of grass and legume herbage is, therefore, very much influenced by its growth stage and also by how much highly lig-

nified tissue it contains. Differences in nutritive value will also occur among grass species and varieties at the same growth stage, if they differ in how much the cell wall has lignified (Jones 1974). Data from Southern Cooperative Series Bulletin 165 (Southern Regionl Research Project S-45, 1971) show that forage quality decreases with age for three widely grown forage types (table 1)—legumes (alfalfa, *Medicago sativa* L.), warm-season grass ['Coastal' bermudagrass, *Cynodon dactylon* (L.) Pers.], and cool-season grass (tall fescue, *Festuca arundinacea* Scheb.). The quality decrease is directly related to the increase in crude fiber, which is inversely related to forage digestibility.

Burton et al. (1963) showed that quality and digestibility of 'Coastal' bermudagrass benefit from frequent cutting intervals. The same study showed that increasing nitrogen fertilization incrased yield, crude protein, and vitamin-A levels but did not affect crude-fiber content. McCullough and Burton (1962) and Stone et al. (1960) have shown that animals respond better to younger forage (table 2). Adjei et al. (1980) evaluated three stargrasses (*Cynodon* spp.) under grazing and found that a high stocking rate (10-15 cattle per hectare) was necessary to maintain good quality forage. But Marten and Hovin (1980) showed that the rate of decline in quality with age differed among four temperate grasses. Decreases in digestibility and crude protein that accompany maturation were least for tall fescue and orchardgrass, *Dactylis glomerata* L.; greatest for reed canarygrass, *Phalaris arundinacea* L.; and intermediate for smooth bromegrass, *Bromus inermis* Leys. So a producer may have some options in selecting the grasses best suited to his livestock needs.

Dry-matter yields of forages increase with age up to about 6 weeks. But the decreases that occur in digestibility and protein content, and the increases that occur in the fiber content make some compromise necessary between maximum yield and desired quality. How these factors are balanced depends on how the forage is going to be used. Forages grown for maintenance of mature animals need not be of highest quality, and harvests may be made for the best yields. Quality of forage is of primary importance if it is to be used to produce animal weight gains or milk, and some yield may need to be sacrificed to maintain quality.

Table 1.—Quality of three forages at various ages[1]

Forage	Digestible energy (kcal/kg)	Total digestible nutrients (%)	Protein (%)	Crude fiber (%)	Digestible dry matter (%)
Alfalfa:					
Immature	3,308	75.0	30.1	17.4	74.0
Prebloom	3,212	72.8	26.6	19.4	74.0
Early bloom	3,117	70.7	23.9	23.2	71.0
Midbloom	2,999	68.0	22.6	24.4	69.0
Full bloom	2,755	62.5	26.5	26.5	67.0
Mature	2,941	66.7	18.9	26.6	68.0
'Coastal' bermudagrass:[2]					
11-17 days	3,069	69.6	20.6	22.2	71.0
18-24 days	2,989	67.8	17.6	25.0	70.0
25-31 days	2,963	67.2	16.3	25.2	66.0
39-45 days	2,963	67.2	11.8	25.8	66.0
53-59 days	2,606	59.1	9.9	27.0	59.0
Fescue:					
Immature	3,359	76.2	20.6	25.0	76.0
Prebloom	3,305	75.0	21.4	24.6	74.0
Early bloom	2,704	61.3	19.4	25.1	70.0
Midbloom	2,994	67.9	14.7	27.9	67.0
Full bloom	3,096	70.2	15.4	24.4	72.0
Mature	3,094	70.2	14.6	25.6	72.0
Overripe	2,512	57.0	9.5	32.0	62.0

[1]After Southern Regional Research Project S-45, 1971.
[2]Fertilized with 580-600 pounds of nitrogen fertilizer per acre per year.

Tropical grasses are generally less nutritious than temperate grasses, possibly because the tropical grasses grow fast and at high temperatures and light intensities. In the humid Tropics, light intensity is generally only a little higher than that in the temperate regions during summer, but the temperature is much higher. This high temperature probably causes the high crude-fiber content and, with the low nitrogen supply, also reduces the crude-protein content (Deinum 1966). Management practices that will improve the nutritive value of tropical grasses include fertilizing with nitrogen and paying close attention to cutting or grazing frequencies to prevent the decline in forage quality that accompanies maturation. And using cultivars selected or bred for improved quality could also be effective. For example, 'Coastcross-1' bermudagrass, which was bred for improved quality, was 12% more digestible than 'Coastal' (Lowrey et al. 1968) and improved animal production by 30% to 50% (Chapman et al. 1972).

FERTILIZER EFFECTS

The effects of fertilization on forage digestibility are not nearly as pronounced as the effects of forage aging. Fertilizer, especially nitrogen, often does improve digestibility slightly, particularly if the soil has low fertility. But nitrogen fertilization increases protein content greatly. For example, 'Coastal' bermudagrass, when fertilized with 0, 100, 200, 300, 600, or 900 pounds of nitrogen per acre per year had a crude protein content of 9.9%, 9.7%, 11.0%, 12.4%, 15.7%, or 17.3% (Burton et al. 1963). Deinum (1966) found similar responses in other grasses. Still, the percentage of protein in most forages will decrease with age even at high levels of nitrogen fertilization.

Mineral composition of plants varies greatly with soil fertility and plant species. And species vary greatly within themselves, so using tables to determine a forage's mineral content is risky. The only safe way is to use chemical analysis of the particular forage. Because plants and animals have different mineral requirements, feed supplements are needed for the animals. Adding minerals as fertilizer will generally increase their levels in the plant. Uptake and plant content of most elements can be influenced by soil pH, moisture availability, and plant species. So liming, irrigation, and drainage, and selection of forage species can influence plant composition.

Most edible whole-plant forage has a concentration of nutrients that is adequate in relation to the digestible energy it supplies (Crampton 1957). Interrelationships exist among digestible nutrient and energy content, voluntary dry-matter intake, and the overall feeding value of forages. Crampton and Jackson (1944), studying the mineral content of several forages, found that their total digestible nutrients had at least enough protein, calcium, and phosphorus to meet the maintenance needs of cattle. So the basic limitation of most forage is the amount of available energy. Fertilization should provide the nutritional needs of the forage plant, but the forage's effectiveness to the animals that con-

Table 2.—Effects of cutting date on consumption and digestibility of hay[1]

Cutting date	Growth stage[2]	Number of cows	Daily hay intake (% of body weight)	Dry-matter digestibility (%)
June 3-4	Vegetative	32	2.72	67.2
June 9-10	Early boot	23	2.64	63.1
June 11-12	Boot	24	2.36	65.7
June 14-15	Late boot	94	2.45	62.6
June 16-18	Early head	24	2.28	58.5
July 1	Bloom	30	2.30	52.7
July 5	Bloom	24	2.13	52.2
July 7-8	Bloom	23	2.05	52.2
July 9-10	Late bloom	24	1.95	51.5

[1]After Stone et al. (1960).
[2]Growth stage of timothy in grass-legume mixture.

sume it depends mostly on how it is harvested and used.

FEED METHOD

Forage can be fed to animals in several ways—through grazing (continuous, rotational, or strip), green chop, hay, pellets, and silage. What method is used affects animal production individually and per unit of area. For example, Hart et al. (1976) found that average daily weight gains for steers feeding on 'Coastal' bermudagrass differed greatly (table 3). Differences among grazing methods in average daily gain were largely accounted for by differences in grazing pressure. Differences among feeding methods reflected differences in forage intake and lignin content of forages. Feed methods will not change the quality of the forage; but some do allow a forage to be maintained in a more nutritious state or to be harvested at the best time to preserve its quality. Harvesting procedures usually reduce forage losses associated with grazing. But the machinery, labor, and energy needed for harvesting are additional costs.

Heaney et al. (1963) found that intake of digestible energy from pelleted forages for sheep decreased as the digestibility of the energy decreased, that pelleted forages had more digestible energy than chopped forages, and that forage age had no consistent effect on changes in digestibility due to pelleting. Chapman et al. (1972) found that age of harvest is a significant source of variation in average daily gain of steers fed pelleted forages. Forage cut and pelleted at 4 weeks gave higher average daily gains and also required less feed per unit of gain than did 8-week-old forage.

RANGELAND FORAGE

The vast areas of rangeland in the world (over 700 million acres in the western United States) are generally characterized by limited rainfall, rough topography, soil deficiencies, or restricting climatic factors such as temperature. Raleigh (1973), studying the chemical composition and digestibility of three rangeland grasses, found that the rates of decrease in quality were generally similar. Precipitation patterns permit only one growth cycle, and there is little difference between species in quality or date of maturity. Lack of digestible protein is likely to be the first factor limiting animal production on the range. Limited rainfall reduces the probability of improving protein levels by fertilization. Digestible energy and feed intake are also often limiting factors due to low quality or low availability of feed. Minerals, especially phosphorus, are often deficient in range forage, but are easily supplied with a mineral supplement. Since intake is related to feed supply, stocking rates should be adjusted to available supply, or supplemental feed should be provided. Calves should be born in the fall so they can make best use of the higher quality spring growth.

Table 3.—Effect of feed method on animals eating 'Coastal' bermudagrass (3-year average)[1]

Method	Animal days/ha	Animal days/ton dry matter	Intake (kg dry matter/ steer/day)	Average daily gain (g)	Gain/ha (kg)
Grazed:					
Continuous	1,009	88	....	594	600
Rotation	1,069	92	....	449	469
Strip	1,245	108	....	392	487
Harvested:					
Green chop	1,749	150	6.2	369	647
Hay	1,473	126	7.7	671	971
Pellets	1,221	105	8.8	800	967

[1]After Hart et al. (1976).

CONCLUSION

Forage plants have inherent potential for dry-matter yields and quality. But the realization of this potential is influenced by management variables. Proper fertilization practices will insure good plant growth and should provide enough minerals in the forage to meet the needs of the consuming animals. Fertilizer affects forage quality less, though nitrogen supply strongly influences protein content. Legumes generally produce herbage of higher quality than do grasses and can produce their own nitrogen. Because age of forage when grazed or harvested greatly affects its digestibility and protein content, its use should be managed to provide the quantity and quality of feed required by the animals. Research should continue to develop better ways to grow and use forages for maximum animal response. And we need to improve the dependability of legumes as forage when grown alone or in combination with grasses.

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